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PREDICTION OF EROSION DUE TO CAVITATION IN HYDRAULIC MACHINES

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ABSTRACT

Recent studies on cavitation erosion, conducted under the European research programme BRITE-EURAM, are synthesised. The technical and economical environment, in which the objectives of the project have been defined, are presented. A technical description including the methodologies used, the work achieved and the main results obtained are summarised.

INTRODUCTION

Cavitation is a well known physical phenomenon which generates erosion in industrial hydraulic machines, All turbomachine manufacturers or users are more or less concerned by this problem.

Pumps, turbines and propellers generally are designed at nominal working points for which a given level of cavitation is tolerated without any subsequent significant damage which would limit the mean time between failures. Nevertheless, even in these circumstances, emergency interventions, such as surfacing of turbine blades, replacement of pump impellers or laying a ship in dry-dock are not uncommon, These cases become more frequent when non-nominal conditions are required : partial load for a pump, variable head for turbines, variable sailing speed for ships. A better control of erosion phenomenon can ensure savings of costs due to production losses and for repairs,

As far as design of new machines is concerned, the possibility of predicting the life of a material with reasonable accuracy could permit : to optimise the size of the machine; to choice the best compromise on the constituent material between its resistance to erosion and its cost of supply; and to reduce the infrastructures needed for operation of the machine (civil works, motorisation, etc...).

These considerations led to determine the following objectives of a European project:

- to provide a methodology of prediction of erosion due to cavitation in hydraulic machines
- to provide a methodology of immediate economic detection of erosive patterns of cavitation applicable on industrial machines.
- to prove that these methodologies are reliable by performing validation tests on model or prototype, in laboratory conditions and on industrial site.

To achieve the stated objectives, a consortium of companies was set up with CERG as leader, with the following organisation :

Four industrial and university laboratories were in charge of defining operating methodologies, analysing data and performing laboratory validation tests : CERG, EDF/DER (France), IMHEF (Federal Polytechnic School of Lausanne, Switzerland) and the Technical University of Darmstadt (Germany).

Four industrial companies were in charge of the application and validation of the methodologies : KSB for pumps (Germany), Riva-Hydroart and ENEL (Italy) for turbines, and the CEHIPAR of Madrid (Spain) for ship propellers.

TECHNICAL DESCRIPTION

Definition of the aggressivity

Considering the complexity of erosion phenomenon, it can be said that a cavitating flow is characterised by its aggressivity - also referred as Hydraulic Cavitation Intensity (HCI) - which is a purely hydraulic quantity, i.e. independent of the constituent material of the machine, One of the bases of this European research programme is to assume that only the knowledge and measurement of this quantity will allow to known the actual risks of any material "damage to be estimated, without knowing the detailed fluid/structure interaction mechanisms involved.

The spatio-temporal pressure field at the boundary of a cavitating flow is in the beginning of the damaging of this solid boundary. The definition of the aggressivity of a cavitating flow must arise from this notion.

This pressure field results from the spatial and temporal random succession of pressure pulses, due to the collapse of cavitating events, which characteristic parameters, namely :

- an amplitude : p
- an application area : s
- an application duration : τ

are also randomly distributed. This pressure field is a random function which can be reduced to the following triple density :

$$\frac{d^3NST(p,s,\tau)}{dp.ds.d\tau}$$

where NST is the number of pressure pulses per unit of area and per unit of time. In the case of steady cavitating flows, this density is independent of the time, but it still varies in space. This triple density may constitute a complete definition of the aggressivity.

Up to now, no existing transducer is able to measure this triple density. Thus, the pitting sample technique used for a long time [1,7, . ..] is adopted as a reference technique. When a material is submitted to an aggressive cavitation, at the first stage of the erosion , pits appear on the surface. These pits can easily be counted. Their size and shape (volume, radius and depth) are directiy dependent to the individual area and pressure of the impacts, Thus, by using material samples as a transducers, it can be assumed that a detailed analysis of such pits provide complete a reasonable estimate of the aggressivity. The pits histograms which provide complete information could, for practical reasons, be simplified to the three following integral quantities : VST, the total volume of pits per unit of area and per unit of time, is a fundamental quantity which is very well correlated with the erosion rate; Rrn and Hm the mean radius and the mean depth of pits,

The methodology of prediction

The problem of predicting cavitation erosion can be split into two steps (fig. 1) :

- step 1 : to predict the aggessivity of the industrial flow considered

In many cases, this step would be carried out directly by means of on-site measurements performed on the machine. But when it is impossible or for machines under design, an indirect procedure is proposed (fig, 2) by transposing the aggressivity measurements performed on a small scale model hydrodynamically similar to the full scale machine.

- step 2: to deduce the real expected erosion from the aggressivity

The aggressivity of the real flow is reproduced on a special test device as far as the pit histogram is concerned, but taking care to generate such pits with a frequency higher than the one expected on the machine. In these conditions, a sample of the machine's constituent material will be eroded on the device by the same mechanisms as those encountered on the machine, but at a faster rate. The calibration of the device by the pit analysis technique should allow to know the acceleration factor and thus the expected real erosion. A appropriate e experimental test loop, the CAVERSIM, built on a vortex flow chamber base, has been used for this purpose.

Works achieved during the BRITE-EURAM project

A set of experiments has been carried out on : a two-dimensional venturi test section; two similar axisymmetric venturi test sections (scale factor 1:3); two similar NACA profiles (scale factor i: 1.7); a 300 kW mixed flow pump and its model (scale factor 1:2); a 33MW Francis turbine and its model (scale model 1:5.2); a 3.5 MW Pelton turbine and its model (scale factor 1:3 .5); a 2.8 m diameter ship propeller and its two models (scale factor 1:8.5 and 1:14).

Flow visualizations, aggressivity measurements and erosion measurements have been performed for various flow conditions or operating conditions. The effects of geometrical scale, flow velocity and material have been tested and analysed.

Different types of remote. as accelerometers, fluctuating pressure transducers, hydrophones and acoustic emission sensors, and different signal processing as RMS analysis, frequency analysis or peaks counting treatment have been investigated in order to try to detect and quantify the hydraulic cavitation intensity.

As far as direct measuring methods are concerned, in addition to the pitting measurements which have been systematically used with several material, pressure pulse measurements have been also investigated.

Erosion tests have been performed in laboratory or observed on real machines. These erosions have been simulated on the CAVERSIM by applying the methodology.

RESULTS

Acoustic emission sensors, put as near as possible to the cavitating spot, and peak counting treatment appear as the most adapted remote sensor and processing to detect cavitation on turbomachines. Even if this technique is not able to make direct erosion measurement, it can be very useful for monitoring and maintenance.

Interesting correlation has been observed between pressure pulses measurements and pitting measurements.

The pitting technique has been developed and improved. The improvements concern polishing, samples mounting (screwed or welded), soft metal layer deposit, tape protection and print technique. The localisation and the size of the pits are automatically measured with a laser profilometer coupled with an specific image processing software.

It has been shown that the rate of erosion is directly proportional to the VST quantity and the mean shape factor Rm/Hm is quite constant with a value of about one hundred. In addition, the interaction fluid/structure can be well characterised by the quantity $R_{0.2}/Ze$ where $R_{0.2}$ is the conventional yield strength of the sample and Ze is the mean liquid/material sound impedance.

As far as the hydrodynamic similitude between prototype and model is concerned, the respect of the exact geometry of the walls, the cavitation number σ and the non-dimensional rotating speed number are of prime importance. But, whenever possible, it is advised to visualise the cavities to make sure that no major distortion occurs.

Concerning the pitting technique, the material deformation must also be in similitude. So, the constant of the following number have been proposed as a preponderant condition of similitude:

$$\pi = U . Ze/R_{0.2}$$

where U is a reference velocity. This result means that it is possible to balance a change of flow velocity by the strength of the material for the aggressivity measurement by the pitting technique.

Assuming the hydrodynamic similitude is obtained and the π number kept constant, the dimensional analysis gives the following transposition laws for the aggressivity measured with the same material :

$$VST_{fs} = VST_{ss} . U_{fs} / U_{ss}$$
$$Rm_{fs} = Rm_{ss} . L_{fs} / L_{ss}$$
$$Hm_{fs} = Hm_{ss} . L_{fs} / L_{ss}$$

where L is a reference length and $_{fs}$ and $_{ss}$ refer to the full and small scale.

Experimental results, particularly those obtained on axisymmetric tests sections, agree very well with these laws,

The CAVERSIM has been calibrated, by measuring the aggressivity with the pitting technique, in a large range of test conditions. It was then shown that all the flow conditions only lead to a narrow range of aggressivity in terms of Rm and Hm, but allow to reach high levels of aggressivity in terms of VST (about 10-9 m/s on a Stainless-steel sample).

To take into account a possible change of pits size between the full scale and the CAVERSIM, the following transposition laws for erosion have been proposed :

$$Z_{fs}(T_{fs}) = Z_{CAV}(T_{CAV}) . Rm_{fs} / Rm_{CAV}$$

and

$$T_{fs} = T_{CAV} (VST_{CAV}/VST_{fs}) (Rm_{fs}/Rm_{CAV})$$

where Z(T) is the erosion depth curve versus time.

Experimental agreement of this alternative procedure have been observed on axisymmetric tests sections, on pump and on propeller,

CONCLUSION

In the past, no reliable methods were available which allowed to predict cavitation erosion or to detect the erosive patterns of cavitation on industrial machines.

Compared to earlier knowledge and state of the art at the beginning of the project, it is now possible to forecast quantitative cavitation erosion by use of measuring techniques and procedures of data processing.

The validated results encourage the use of the methodology of prediction and of the measuring techniques. These results give a common basis usable by the scientific community to continue research and development and applicable by manufactures and users for industrial application to hydraulic machines and components,

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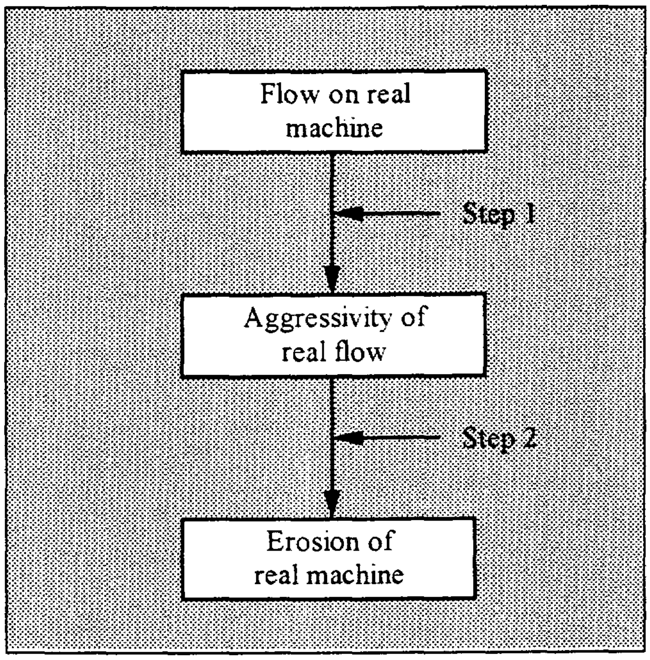
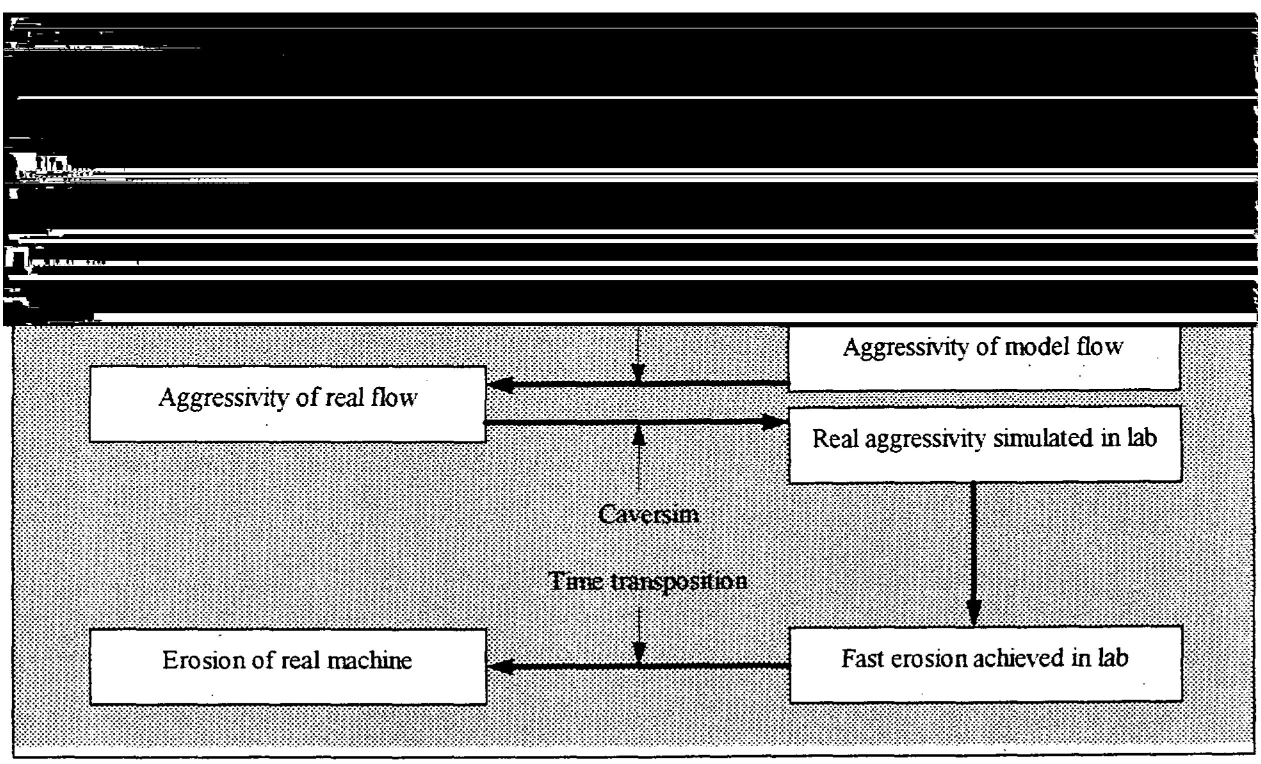


Fig. 1: Prediction methodology comprising two basic steps : predicting aggressivity then predicting erosion.



Fig, 2: Complete prediction methodology diagram.